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A WIND PLANT TO POWER SEA SIGNALS

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16. Abstract

On the basis of the experience with the Schleimunde wind-power plant, it may be said in conclusion that economic operation of such a wind-power plant is feasible whenever, on the one hand, the cost of connecting the consumers to the public network is prohibitive, and on the other hand sufficient wind is available. The planning of long-term duration and force readings is of particular value. It is advantageous to erect wind-power plants in coastal and mountain regions.

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A WIND PLANT TO POWER SEA SIGNALS

by Friedrich Baumeister[1]

For decades engineers have been striving to exploit wind energy for generating electricity. Plants producing up to 1000 kW have been constructed abroad, particularly in the USA, the USSR, and the U.K. German wind-power plants, with substantially lower outputs, mainly for supplying electricity to remote farms, etc. have been produced for use both in Germany and abroad. A plant developed for supplying the public is still in the research stage. This article deals with a particularly interesting wind-power plant on the German Baltic coast. /437*

FORERUNNERS OF WIND-POWER PLANTS

As far back as 1903 a wind engine driving a transmission connected to machine tools was built in the building yard of Husum's Waterworks; three years later a 115/160 V, 60 A shunt-wound generator was added to the six-blade 15 m diameter wind wheel, with a gear transmission connected between them. The generator supplied an independent network and a 209 ampere-hour battery with a discharge time of ten hours. A shunt regulator served to equalize voltage fluctuations in the network due to irregular running. A relay prevented the battery from discharging through the generator, and conversely current surges due to excess voltages on the engine were used to charge the battery. Voltage

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*Numbers in the margin indicate pagination in the foreign text.

[1] Dr. F. Baumester, Engineer, of the Government Building Council, is the head of the Kiel Water and Navigation Office.

oscillations did nonetheless occur in the network, the main effect of which was to diminish the service life of the incandescent lamps on the circuit. A double-battery switch was later added to regulate the battery.

The battery was placed once more in 1920 with a capacity of 290 ampere-hours. Previously a diesel set had been used to charge the battery when the wind dropped. In particular, the battery powered eight machine tools and lighted the building yard. When the battery was exhausted once more in 1930 the entire plant was shut down.

Except for a few months in 1911, when the wind wheel was damaged by a severe storm (wind force 10-11) the wind-power plant ran satisfactorily for nearly 27 years.

In 1926 a wind-power plant to supply current to the same consumer was built on Neuwerk Island in the Elbe estuary, on which there were a tower with beacons for guiding ships into the Elbe, seven farms, and other buildings. In those days there was an Adler turbine made by a manufacturer from Heide i.H. with an 8 kW generator charging a 220 V battery of 440 ampere-hour capacity. In December 1946 the electric plant was destroyed by fire and a few months later the wind wheel was destroyed by a storm.

In 1948 a new wind-power plant was erected on the same spot. The three-bladed wind wheel is 12 m in diameter and is mounted on a 20 m mast. It drives a 14 kW d.c. generator which charged a 220 V storage battery with 648 ampere-hour capacity. The highest power output is attained with a wind velocity of 8 m/s (=5 on the Beaufort scale). A compass-card turns the wind wheel in the wind direction while during storms the wind wheel is turned out of the wind by a baffle/diaphram plate. When they rotate too fast, the blades are automatically feathered. When the wind drops, two diesel motor sets, 37 kW and 12 kW, take over. The plant is serviced by the public power utility.

THE WIND-POWER PLANT ON SCHLEIMUNDE ISLAND

Background

On Schleimunde Island in the Lotsen group, at the mouth of the Schlei, an inlet carved deep into the Schleswig-Holstein east coast between Flensburg Forde and Eckernforder Bay, there has been for many years a lighthouse to identify the artificial inlet between piers, to which a /438 directional light for navigation on the Schlei, a hand-operated compressed-air fog horn, a gale warning device, a customs station, and a refuge harbor have been added. The question was one of supplying all these facilities with electric current.

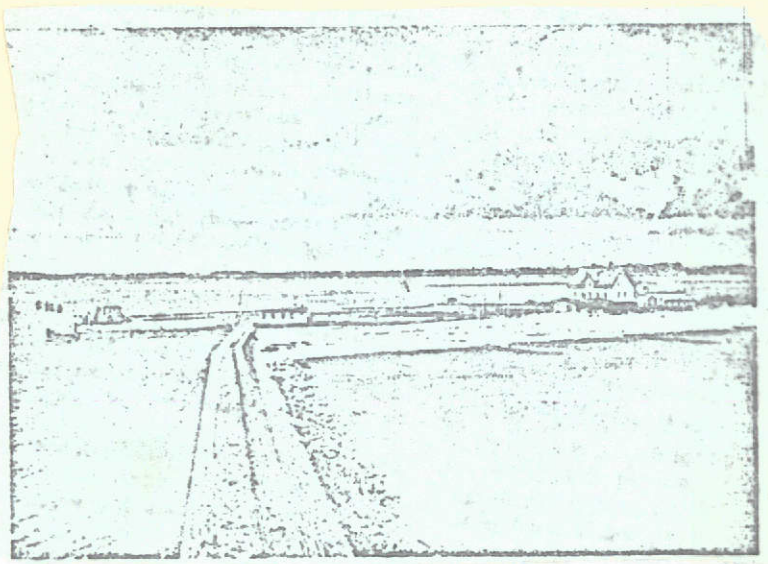


Fig. 1. View of Schleimunde Island, as seen from the pier.

The small range and infrequency of the fog signal (which sounded only every minute and, even then, only in daylight and had to be operated by hand) gave continuous cause for complaint by shipping and fishing interests. Since it was desired to improve the existing beacon signaling system as well as the customs signal, and since the three families dwelling on the island (lighthouse-keeper, harbormaster, and pilot) needed better living conditions, plans and investigations were made in the postwar years (from 1949) to provide the island with electric current. There were several possibilities: bringing current from the mainland south or north, setting up a diesel plant, or erecting a wind-power plant.

Economic Considerations

To erect a 2.2 km long 14 kV line on spun concrete poles from the south and lay a 400 m submarine cable under the Schlei inlet would have cost about 48,000 German marks in 1951.

A 4.5 km high-voltage line of the same type, which would have had to cross the old mouth of the Schlei, somewhat silted up, in the north, would have required about 37,000 marks at the same period. On the other hand, a diesel set of the required size would in those days have cost about 7000 marks, a wind-power plant plus accessories about 15,000 marks. In each case the costs of running electric lines to all connecting points, a standby generating set, control panel, and engine house, would have to be added to these amounts.

A favorable factor for independent current supply was that, at the same time, a lead storage battery with a capacity of 256 ampere-hours (six-hour discharge) for a main navigation beacon east of the Kiel Forde became available when this beacon was hooked into the public network. Only if a new storage battery needed to be procured, and therefore with current supply from the network, the control panel and engine house could be somewhat smaller in size, could there be considerable cost savings in running the plant if a wind energy plant were chosen.

It was also discovered that the operating and maintenance costs of the wind-power plant would be less. The favorable experience with the plant described above on Neuwerk Island was the decisive factor in opting for the wind-power plant. Moreover, with such a plant technical and economic bases for further wind energy utilization plans could be investigated and experience accumulated.

Wind Conditions on Schleimunde

Another advantage was that a twenty-five year series of wind observations (1914 to 1938) was available for Schleimunde. Under the auspices of the gale warning service the wind velocity was estimated by the Schleimunde pilot station three times a day as a rule (8:00 a.m., 2:00 p.m., and 8:00 p.m.). With wind force 6 and more, intermediate readings were taken as often as every two hours.

According to the readings collected and evaluated by the North-West Germany Weather Bureau, Schleimunde showed a yearly average wind force of 3.4 Beaufort or 5.3 m/s, with a prevailing west wind but approximately equal forces from winds in all directions. This gave the basis for planning and efficient operation of the plant. By comparison with the evaluations of wind conditions made by the German Meteorological Service in cooperation with the "Wind Energy Research Association, Inc.," Schleimunde proves to be one of the most "wind-favorable stations," as the following table of comparisons with average wind velocities of neighboring locations shows:

Helgoland . . . . 6.7 m/s
Brunsbüttelkoog . . . . 5.1 m/s
Hamburg-Fuhlsbüttel . . . . 4.4 m/s

Table 1 gives information on the frequency of wind forces, especially wind forces usable for the wind-power plant:

Table 1. Frequency of Wind Forces

Wind force (Beaufort Scale)	0...1	2...3	4...5	6...7	8...9	10...12
			usable			
Average frequency (as % of hours in a year)	8.0	49.0	25.9	13.6	3.3	0.2
		74.9				
			88.5			

The frequency of usable wind forces from 2 to 5 Beaufort is about 75%; if we add in wind forces up to 7 Beaufort we reach 88.5% of all the wind in the course of a year. These findings justify the hope that the wind-power plant designed by Allgaier Werkzeugbau GmbH will provide enough energy for the island's needs.

Energy Requirements

The power requirements of the island are assumed to be as follows:

3 beacons, including lighthouse . .	250 W
Gale warning signal	80 W
Air-powered signal	850 W
Harbor and engine room lighting . .	150 W
4 houses, 1000 W each	4000 W
Customs stations	670 W
	6000 W

Thus the beacon and signal facilities account for about 2 kW and private consumers about 4 kW. On the average the consumption in good visibility conditions and normal light usage is 2 to 2.5 kW.

Energy Supply

In view of the wind conditions, the 6 kW plant is suitable for supplying current. The wind begins to be usable with a wind force of 2 to 3, producing about 0.5 kW, and rises with increasing wind velocity to the peak power value of 6 kW, achieved with wind force 5. Through automatic adjustment of the blade position, which will be described below, this power output can be maintained up to about wind force 8. With even stronger winds the plant shuts off automatically by means of the so-called "storm stop" to avoid overloading the engine.

The power output of a wind energy plant is calculated by the formula

$$N = 0.000285\ v^3\ d^2\ \eta (\mathrm{kW}),$$

where v is the wind velocity, d the wheel diameter, and η the efficiency of the assembly.

Tests show that the total efficiency η of the plant, including the electrical portion, can be written as 0.63. With the annual average wind velocity of 5.3 m/s and a wheel diameter of 10 m, the average power output amounts to:

$$N = 0.000285 \times 5.3^3 \times 10^2 \times 0.63 = 2.68 \text{ kW}.$$

The average current requirement for the island (an average of 2.5 kW) can thus be covered in all cases by the 6 kW plant. Peak requirements exceeding 6 kW in exceptional cases can be met by switching on a standby diesel assembly (one-cylinder diesel engine, 5.5 HP with 3 kW generator). This may also be resorted to when the wind drops. However, only the sea mark and signaling systems can be supplied with the smaller output of the diesel engine. /439

Of course the battery can be charged to full capacity to store current so that it covers the entire needs.

PLANT CONSTRUCTION

The wind-power plant consists of a 10 m hollow mast, anchored and guyed into a concrete foundation, with a three-bladed wind wheel mounted at the top (Figures 1 and 2).

Propeller Adjustment

The propeller blades are made of sheet steel and are hollow; they are weatherproofed with baked enamel inside and out. At their roots the three propeller blades are rotatably mounted on a swash plate. Adjustment is made by three technical devices independent of one another:

1. by a mechanical self-locking hand crank at the foot of the mast, operated manually, which actuates a fork lever with adjusting ring through a crank lever and cable;
2. by a centrifugal governor which directly acts on the control shaft and the swash plate;

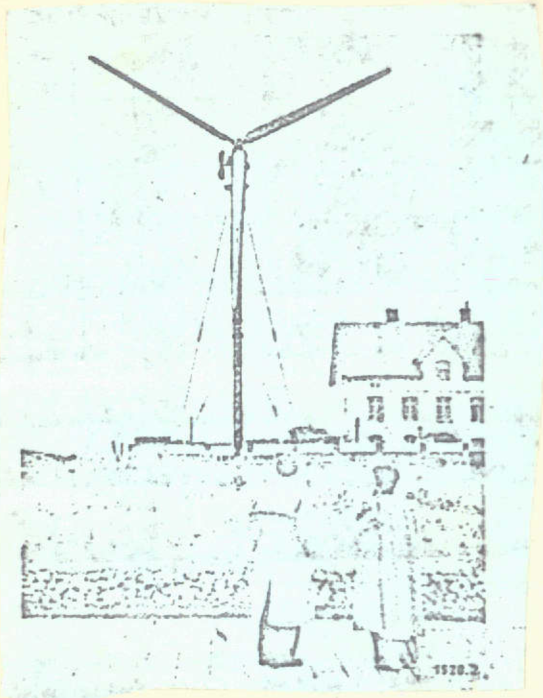


Fig. 2. The wind-power machine on Schleimunde Island.

3. by the automatic hydraulic positioning of the blades according to wind conditions or by the voltage regulator controlled from the control panel via an electromagnetic valve.

The wind-power plant is turned on and off manually with a crank. The blades can be turned freely from the feather position (zero angle of attack)into the fully automatic drive position, or be placed at a set angle of attack. The latter position gives a fixed operating rpm not affected by the centrifugal governor.

If the blade adjustment is set to operate completely automatically, the blades initially move to the "starting position." Then, driven by spring force, they assume the favorable angle of attack required for low wind forces and can use the dynamic wind pressure to start up the propeller. At the same time the blades adjust themselves automatically to the correct position, as does the propeller rpm. An eccentric pump mounted on the drive shaft then pumps oil continuously into a spring-loaded pressure cylinder. The control shaft, likewise spring-loaded, moves by piston action through a system of levers according to wind conditions and thus acts upon the swash plate which angles the blades via the push-rods.

The maximum (86) rpm with wind forces over 4 Beaufort is kept constant by the centrifugal governor, which runs off the gear train at 17.5 times the speed of revolution and thus develops the

Wind direct

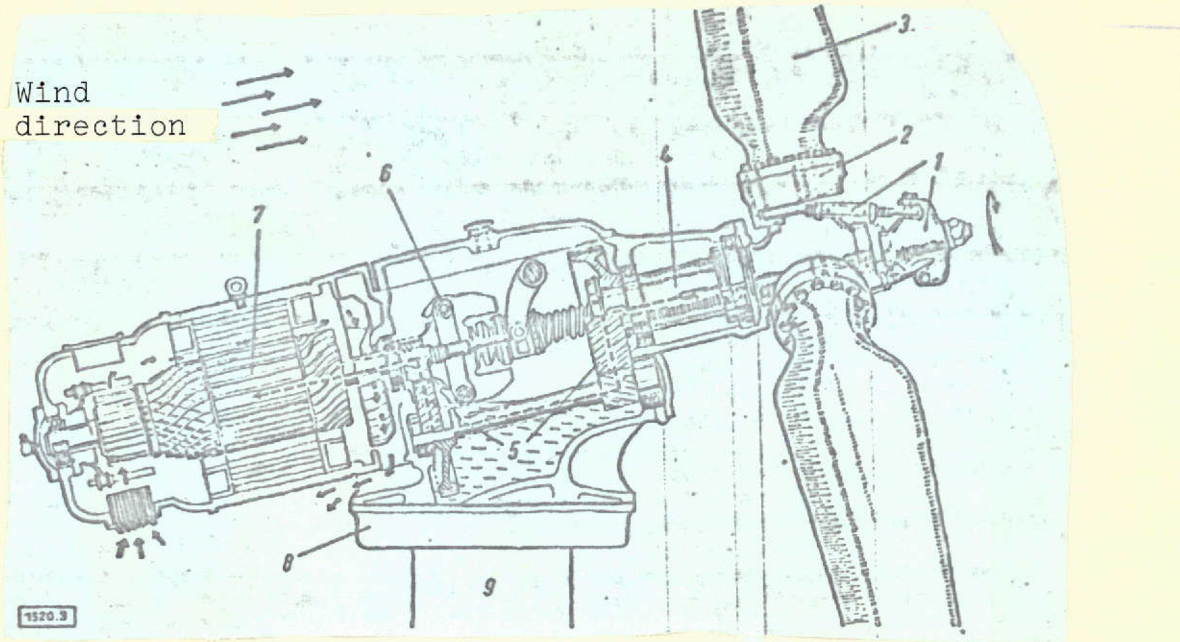


Fig. 3. Section through wind-power machine.
1. swash plate with push-rods for adjusting blades. 2. swivelling blade root mout. 3. blade. 4. main shaft. 5. 1:17.4/6 gears. 6. centrifugal governor. 7. D.C. generator. 8. tower head bearing with adjusting device. 9. hollow guyed steel mast, diameter 10 c.m.

forces necessary for control (Figure 3). The flyweights press with thumb-shaped levers on a pressure plate, which in turn moves the springs and levers mounted on the control shaft and influences the axial rotation of the blades so as to give them a greater or smaller angle of attack.

After the propeller has started the blades are set by the uniform oil pressure of the pump. The stream of oil flows continuously into the pressure cylinder and flows continuously out through a bypass channel. When the feed is uniform the pressure piston in the cylinder does not move. If a greater or lesser amount of oil is delivered due to a change in rpm, the piston moves, changing the position of the control shaft of the swash plate via the fork lever, and hence the position of the blades.

The so-called storm stop is built into this oil circuit. /440 A movable disc exposed to the wind opens a valve in the oil circuit when an adjustable maximum wind force is exceeded. The oil pressure in the pressure cylinder immediately drops to zero and the spring tension pushes the blades into the feather position. After a short time the starting mechanism switches the blades back to the starting position and the propeller again delivers power to the generator as long as sustained wind force is not continuously acting on the storm stop.

A further opportunity to influence the blade setting is provided by the solenoid valve built into the oil pressure cylinder and controlled from the control panel. At the control panel the voltage to be developed by the generator can be adjusted by a potentiometer. If this voltage is exceeded by an increased propeller rpm or when the voltage necessary for charging the battery or for developing the desired line voltage (when the plant is directly into the line) is reached, the solenoid valve in the pressure cylinder oil circuit is activated. The oil pressure drops and the propeller blade control, already described, cuts in.

To ensure continuous automatic blade adjustment, a minimum amount of oil (up to the height of the suction pump) must be maintained in the transmission housing.

Electrical Devices.

The propeller drives the generator flanged directly to the head housing through a two-stage helical spur-gear drive with a transmission ratio of 1:17.5. The entire head of the unit is mounted on a turntable which can turn through an angle of 360°. A small side-mounted wind vane turns it in any wind direction.

The current is picked off by slip-rings and conducted by cable to the switching apparatus and thence to the control panel

(Figure 4). A reverse-current tripping relay at the switch prevents current from flowing back from the battery to the generator when the wind is low or when the plant is in the stop position. At the same time the activating voltage of the solenoid valve is set by a potentiometer, via the over-and-under voltage relay of the switch.

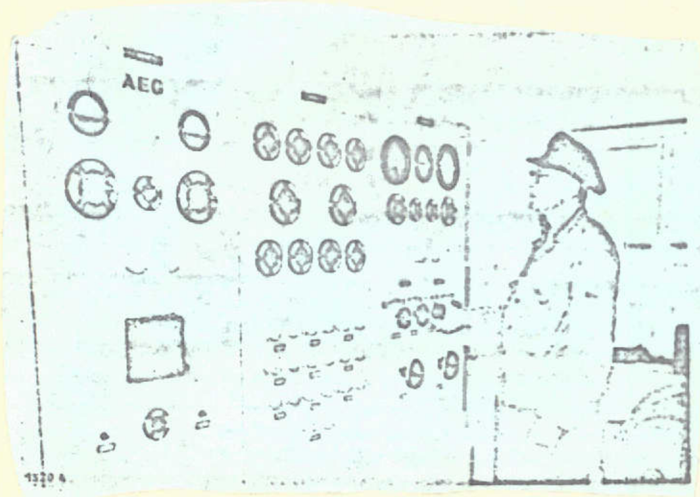


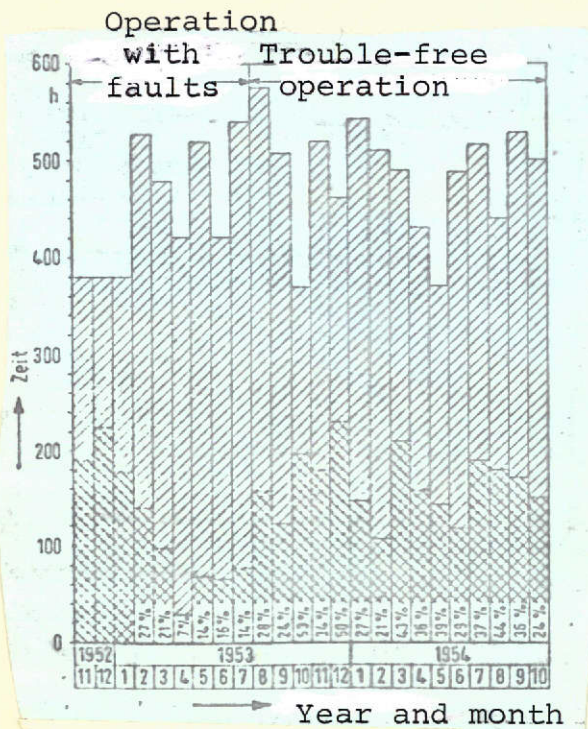
Fig. 4. Wind-power plant control panel.

A Pohl switch is added to protect the battery from overcharging. Since consumer current is only taken from the battery, an automatic double-battery switch is placed in the charge-discharge line of the battery, which makes it possible to charge and discharge simultaneously by means of regulators. The consumer voltage, which is moreover kept at a constant 110 volts by the double-battery switch, is conducted via the master control panel to the individual consumers. When the current drops it can be withdrawn from the individual consumer circuits via a distribution panel.

OPERATIONAL EXPERIENCE

The wind-power plant was started up at the end of October, 1952. After faults--practically unavoidable with newly-developed plants--had been eliminated in the first months of operation, it has since run smoothly (i.e. since early August, 1953) and fulfilled expectations. Accordingly, the period of trouble-free operation (i.e. a full 15 months up to completion of this report in November, 1954) is used as the basis for evaluating the plant and determining its economics.

In the time covered by this report, there have been altogether 7389 usable wind hours (wind force 2 through 7), i.e. 67.5% of the hours during the 15 months. Of these 7389 hours, 2472 were used for power generation (Figure 5). The average energy supply amounted to 492 hours/month or 16.4 hours/day. Of this, however, an average of only approximately 165 hours/month = 33.5% could be used, since there was no need for more current at the time, although in the meantime the consumption in the households had risen considerably due to the purchase of electrical applicances by the three resident families.



Actual wind use as % of wind incidence

Useful wind (wind force 2 - 8 Beaufort

Fig. 5. Comparison between wind availability and wind use.

In addition, in 1954 the government set up an automatic wind recorder to obtain more precise wind readings in the future. At present the consumption is about 9.5 kW, but it never charges the battery simultaneously. The available current is also used to charge the starter and light batteries of the government-owned motorboats based on the Schlei and the battery of the automatic sea-level recorder near the island.

The wind-power plant outputs during the 15 months covered by the report amounted to the following:

Wind engine (3.5% wind usage) . .	5546 kWh	=	94.5%
Diesel set	326 kWh	=	5.5%
Energy supply = energy demand	5872 kWh	=	100.0%

Of the total power generated, however, only 4016 kWh (68.5%) were profitably put to use, while the remaining 1856 kWh (31.5%) were lost through charging the battery. Of the use consumption, 2412 kWh (60%) were for the beacon and other signals, and 1604 kWh (40%) for private purposes. During these 15 months, the beacon was operational for about 5900 hours, so that public services /441
accounted for an average of 400 W per hour.

For other purposes the hourly average was about 150 W, so that the average daily requirement amounted to

$$
\begin{aligned}
12{,}400 &= 4.8 \text{ kWh} \\
24{,}150 &= \underline{3.6 \text{ kWh}} \\
& 8.4 \text{ kWh}
\end{aligned}
$$

With a battery capacity of 256 ampere-hours and a voltage of 110 V, its available energy amounts to about 28 kWh, so that at full discharge it would cover three days of average demand, without the air-powered signal. As a rule, however, it was charged for 5 to 6 hours per day.

However, since the demand for current sometimes rose sharply in foggy period, e.g. in October 1953 with a prolonged calm, a small fraction of the demand was covered by the diesel set. While average wind-power generator output was 369 kWh/month, the diesel set produced an average of only 22 kWh/month.

If the available wind were fully exploited, the energy produced by the wind-power machine during these same 15 months could have been stepped up to about 16,600 kWh, i.e. tripled, if energy consumption or storage could have matched the wind incidence. In particular, the air-powered signal could probably have been powered entirely by wind in foggy periods.

For this reason, the wind, which costs nothing and is insufficiently exploited, should be used more fully by setting up a second (steel) battery with 220 ampere-hour capacity and adding more consumers. Among other things, it is planned to improve the living conditions of the three families by providing water with electric pumps. There are also thoughts of expanding the harbor lighting and, at least during the transition time, to heat electrically the engine house, the harbormaster's office, and the houses. Fuel savings are a considerable factor as it is quite expensive to bring fuel to the island.

Operating Costs and Economics

A comparison of the operating costs of the wind-power plant with those of earlier facilities, and of bringing in current from another point, as well as power generation by a diesel set alone, gives the following picture:

	German Marks (rounded)
1. Earlier operation (liquified gas for the main beacon and petroleum for the directional lights, signals, and lighting):	
353 kg liquified gas (4.40 marks/kg including transportation from Rendsburg-Saatsee).	1553.00
372 liters petroleum (0.60 marks/kg)	223.00
	1776.00
2. Off-island current with emergency plant.	
Basic charge for installation, 750.00 marks/year X 1.25	937.50
Current consumption, 2412 kWh (0.12 marks/kWh) . .	289.50
	1227.00

3. Independent supply (principal current) with diesel set and battery.

1800 kg diesel fuel (0.35 marks/kg)	630.00
Lubricants, grease, etc.	70.00
	700.00
Less current purchase by private consumers (as in 4 below)	275.00
	425.00

4. Independent supply by wind plus diesel plant with battery (as indicated)

152 liters diesel fuel (0.35 marks/liter)	53.00
50 liters engine and gear old (1.20 marks/liter) . .	60.00
400 liters dist. water for batteries (0.12 marks/liter)	48.00
	161.00
Less current purchase by private consumers	275.00
surplus	114.00

It can thus be seen that in the last 15 months used as a basis for the economic calculation, the wind-power plant has given a small surplus over operating costs.

SUMMARY

On the basis of the experience with the Schleimunde wind-power plant, it may be said in conclusion that economic operation of such a wind-power plant is feasible whenever, on the one hand, the cost of connecting the consumers to the public network is prohibitive, and on the other hand sufficient wind is available. The planning of long-term duration and force readings is of particular value. It is advantageous to erect wind-power plants in coastal and mountain regions.